Study of electronic circuits of an Electrocardiogram system

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Abstract – This work presents an experimental evaluation of an Electrocardiogram electronic circuit. Electrocardiography is a health examination in the area of cardiology in which it is recorded the variation of the electrical potentials generated by the electrical activity of the heart, the Electrocardiogram (ECG). To perform this examination, sensitive electrodes are placed at specific points on the body to record the electrical activity caused by the variation in the cytosolic concentration of calcium, sodium and potassium ions [1]. Subsequently, the diagnosis is made by the information of peak of waves and intervals of time of the obtained signal. The ECG can be obtained in a non-invasive way (external to the human body), safe and low cost, and has as main advantage to provide quick and accurate information for analysis and diagnosis of cardiovascular anomalies. In this way, this work aims to design an electronic circuit capable of amplifying and filtering these signals in such a way that the signal resulting from the activity is analyzed correctly.

Keywords-ECG, Filters, Instrumentation Amplifier, Signals Acquisition

I. INTRODUCTION

The heart is made of muscle tissue (myocardium), and is the main organ of the cardiovascular system. It is considered as the propelling pump of bloodstream capable of boosting varied volumes of blood, with autonomous mechanisms of control, according to the needs of the body's tissues. The adult heart contracts and relaxes 115,000 times a day, boosting 7,500 liters of blood through the body [1, 3].

The electrical stimulation for myocardial contraction originates in a small cluster of special cells called the sinus node. These cells have the characteristics of automaticity and rhythmicity, generating the electrical impulse that spreads through the musculature. The result of this electrical activity is the contraction of the musculature in an orderly and coordinated way, guaranteeing the maintenance of this vital function [1, 3].

The electrocardiogram (ECG) is the graphic representation of the heart's electrical potential variations, which can be obtained in a non-invasive way (external to the human body), safe and low cost, and whose main advantage is to provide fast and accurate information for analysis and diagnosis of anomalies and / or cardiac malfunction [1, 3].

Since this electrical activity results in low amplitude signals (0.5 to 4 mV), the analysis of the same is impaired because it is affected by several sources of interference [1, 3]. Since an electronic circuit is necessary to amplify and filter these signals aiming a correct reading of the activity signal, in this work the low cost and simple electronic blocks were designed and characterized.

II. ELECTROCARDIOGRAM

The ECG is the record of the potential variations created in the body by the electrical activity of the heart. The depolarization wave, due to the sequential activation of the cardiac chambers, generates a potential difference between the active and resting zones, which induces electrical field variations that appear as waves in the ECG [3]. In medicine, the ECG is considered an inexpensive, routine, non-invasive, non-contraindicated registry that is part of the cardiological checkup, offering a lot of information.

The ECG is used to assess heart rate and heart rate behavior, allowing identification of changes in heart rhythm and disturbances in electrical conduction of the organ muscles. Figure 1 shows an ECG cycle, when captured with electrodes on the right and left arms, with a potential reference on the right leg.

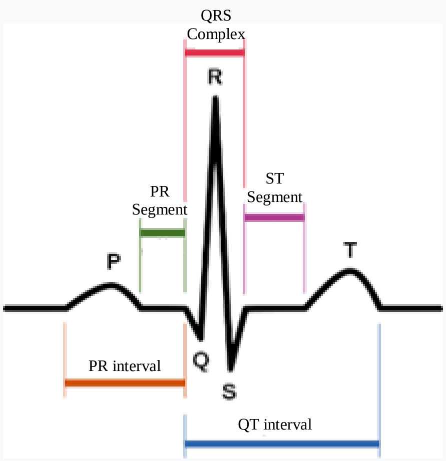


Figure 1 - Representation of an electrocardiogram cycle

The ECG representation is well recognized by means of the most common signs that make it up, called P wave, QRS complex and T wave. These signals represent, respectively, electrical activation in the atria, depolarization and repolarization of the ventricles. The ECG signal morphology, including the intervals between its main constituents, are some indicators of normal heart function.

III. SIGNAL ACQUISITION

A. *Einthoven Triangle*

Einthoven, a Dutch physiologist, may be considered the precursor of cardiology. In 1895, he calculated the exact shape of the curve for the deduced cardiac electrical current from the surface. He also conceived the electrocardiographic tracing in the form of a Cartesian system, converting it into the graphical record of amplitude of the cardiac electrical potential as a function of time. Thus, he defined the velocity of 25 millimeters per second as the standard for the abscissa and the ordinate, standardized that the displacement of one centimeter would correspond to the voltage difference of one millivolt. Conceived at the beginning of the 20th century, these parameters have become consecrated and are used until today [2].

The physiologist called the tracing waves [Figure 1] of P, Q, R, S, and T, randomly. Assuming that the electrical potential generated by cardiac activity spreads to the surface of the body, Einthoven chose the hands and left foot as points of contact with the skin to obtain the signals. These three extremities (right arm, left arm and left leg) form the so-called Einthoven triangle, as seen in Figure 2, at the center of which the heart is ideally situated. The choice of these points generated three possible combinations of electrical records, now called bipolar leads I (the two hands), II (right hand and left foot) and III (left hand and left foot) [2].

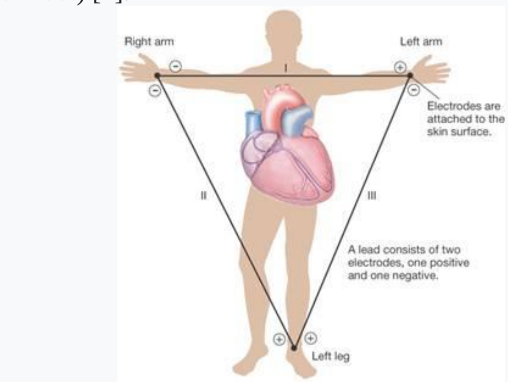


Figure 2 - Einthoven Triangle

B. *Acquisition System*

An important point to consider regarding the acquisition of the ECG signal and its processing is noise. Different types of noise can compromise the signal. Some examples are electrical network interference, electrode contact noise, movement, other muscle contraction, base drift, amplitude-for-breath modulation, instrumentation noise, and electro-surgical noise.

For the acquisition of the electrocardiogram signal an acquisition circuit was constructed, consisting of the following parts shown in Figure 3.

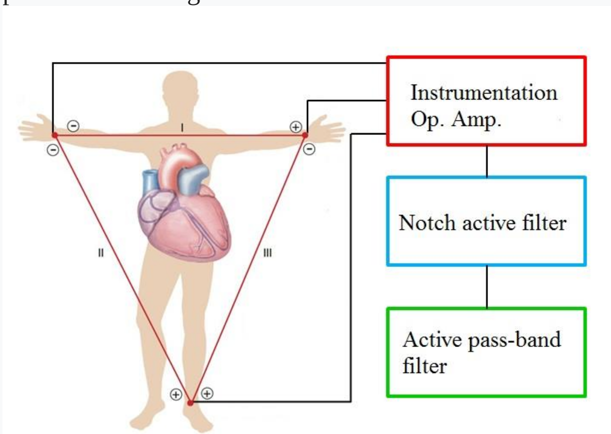


Figure 3 - Block diagram of the system.

The main specification of the blocks is as following:

• Instrumentation Amplifier;
• Notch 60Hz filter;
• High pass filter from 0.5 Hz to 0.1 Hz;
• 120 Hz Low Pass Filter.

C. *Instrumentation Amplifiers*

Instrumentation amplifiers are precision differential amplifiers. These devices amplify the difference between the two inputs, rejecting what is common to both, thus offering a high common mode rejection rate (CMRR). Instrumentation amplifiers are used in areas such as measurement, data acquisition and medical applications, where direct current and gain accuracy are essential. Figure 4 shows the schematic of a typical instrumentation amplifier.

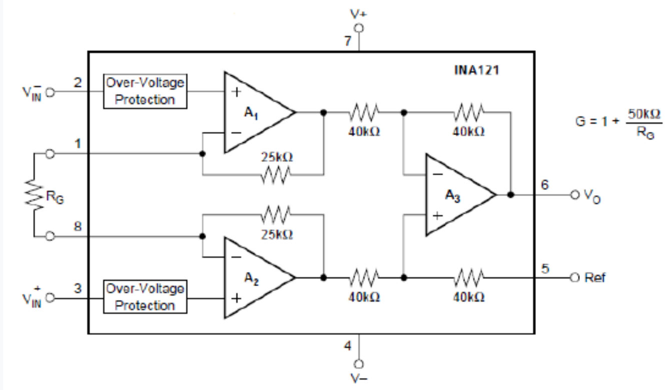


Figure 4 - Instrumentation Amplifier (INA 121)

The INA 121 operational amplifier must be supplied with a symmetrical voltage of at least 5 V, designed with a variable resistance of 0 to 1 kΩ to obtain different gains for operation in patients and in didactic mode (signal generator). These values result in a gain of approximately 51 (didactic mode) and 501 (patient), according to Equation 1.

$$G = 1 + \frac{50k\Omega}{R_G} \tag{1}$$

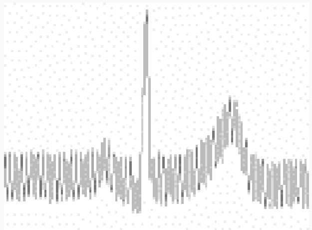


Figure 5 - Cardiac signal amplified by INA 121.

The signal obtained at the output of the INA 121 is amplified together with the noise that makes it impossible to detect the peaks P and S, thus requiring the active filters (figure 5) for more accentuated attenuation in the cutoff band, with lower filter order.

The amplitude characterization of the instrumentation amplifier is given by Figure 6.

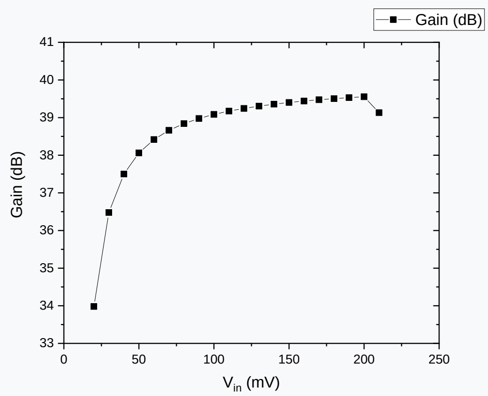


Figure 6- Amplitude Characterization

D. Active Filters

Filters are electronic circuits that perform signal processing, specifically attenuating or emphasizing the characteristics of a given frequency range. They can be classified as assets and liabilities. Active filters have the advantage of having no inductors, thus avoiding electromagnetic effects that compromise the desired characteristics. They also allow the control of input signal amplification and are used when gain and physical size are important for the application.

E. Notch Filter

The notch filter, also known as reject-band or band reject, attenuates a specific frequency band, letting frequencies pass above and below that band. It is used in various applications, including medical equipment, to eliminate the 60 Hz noise present in the electrical network. The frequency response of this filter forms a downward spike in the frequency zone to be rejected. Figure 7 shows the projected notch filter circuit that has a second order Bessel topology. Figure 8 shows the signals before and after the proposed filter and it can be noticed that the signal, where the filter was considered, resembles the ideal signal, being possible to define all the remarkable points of the ECG signal.

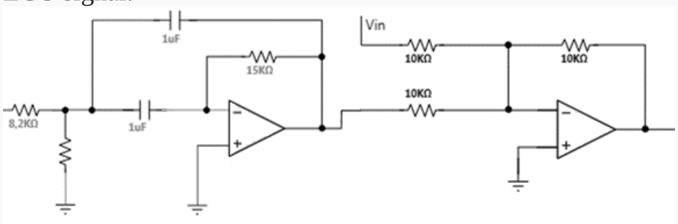
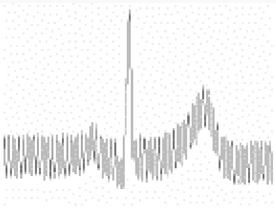
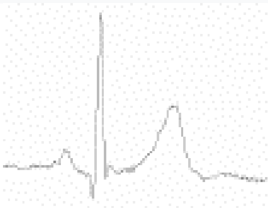


Figure 7 - 60 Hz Notch Filter



a) Signal with 60Hz noise



b) Filtering Signal

Figure 8 -Cardiac signal

The frequency characterization was performed in order to see the accuracy of proposed Notch filter, that it should reject only the sine of 60 Hz. A good response was obtained as can be seen in Figure 9.

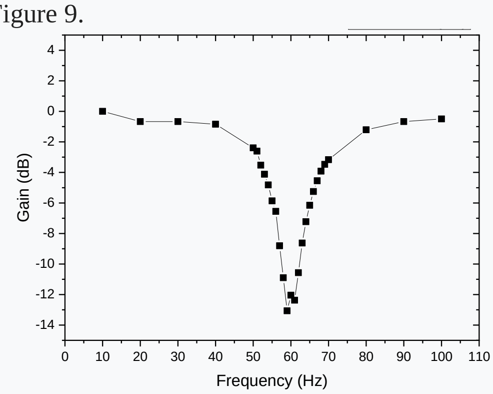


Figure 9 - Frequency Characterization of the Notch Filter

F. High Pass Filter

The high pass filter was designed for a 0.5Hz - 0.1Hz passband with second order 2V / V gain with Bessel topology in order to block the DC signal and remove the oscillation from the baseline. The circuit corresponding to the high pass filter is shown in Figure 10.

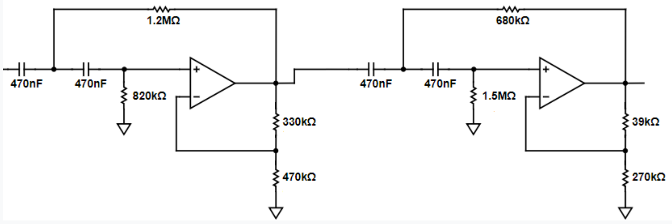
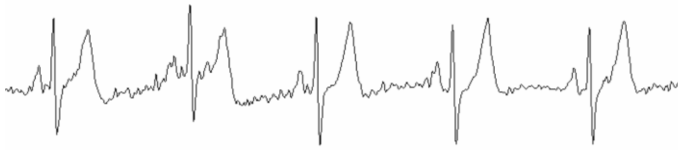


Figure 10 - High-pass filter circuit

Figure 11 shows the signal with and without network noise and the frequency response after the 60Hz rejection band. Cardiac signal after the high-pass filter block is shown in Figure 11b.

a) Baseline oscillation signal



b) Signal filtered by high-pass filter

Figure 11 - Cardiac signal with (A) and without (B) baseline oscillation

Figure 12 shows the frequency response of the high pass filter

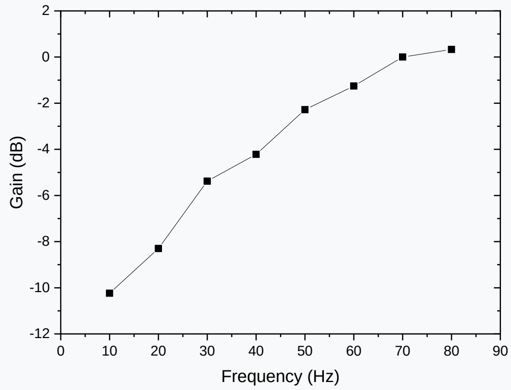


Figure 12 - Frequency response of the high-pass filter

G. Low Pass Filter

The low pass filter was designed for a 40Hz - 200Hz passband, second order 2V / V gain and Bessel topology to filter out muscular noise. The circuit corresponding to the low pass filter is shown in Figure 13.

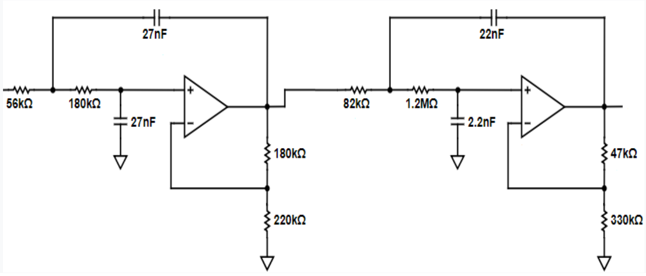
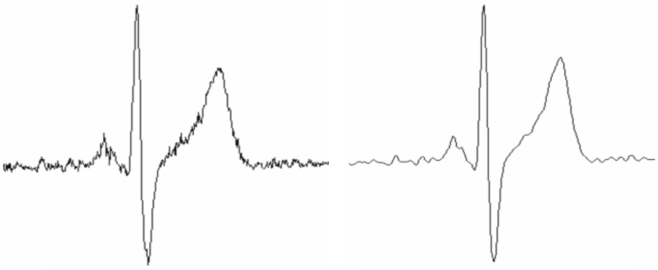


Figure 13 - Low-pass filter circuit

The same procedure was performed considering the low pass filter and the response of this electronic block can be seen by figures 14 and 15. The cardiac signal after the high-pass filter block is shown in Figure 13b and the frequency response of the high pass filter in Figure 15.



a) Cardiac signal with muscular noise

b) Cardiac signal without muscular noise

Figure 14 - Cardiac signal with and without muscular noise

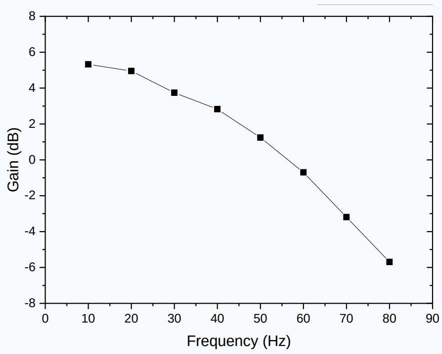


Figure 15 - Frequency response of the low-pass filter

Concatenating all the circuits in sequence as proposed in Figure 3, results the circuit of Figure 16, while Figure 17 shows cardiac signal with noise after amplification (Figure 17a), the output sign showing the cardiac signal without noise (Figure 17b), comparing it with a synthetic perfect cardiac signal (Figure 17c).

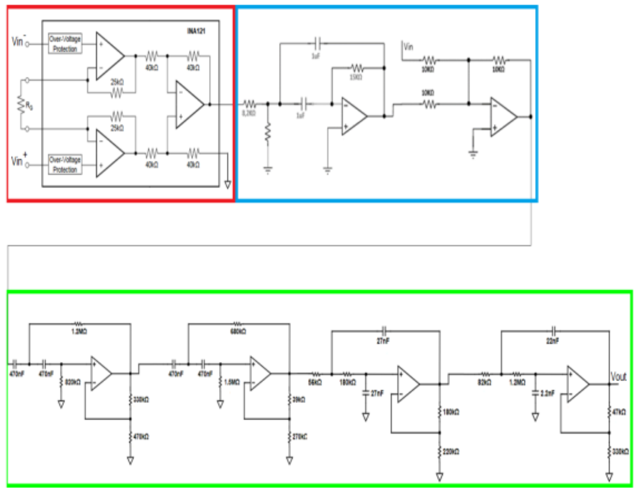


Figure 16 - Implemented Electronic circuit

a) Noise signal **b)** ECG output signal **c)** Cardiac signal

Figure 17 – Biologic and Synthetic Cardiac Signal

IV. FINAL CONSIDERATIONS

The proposed circuit was evaluated experimentally and adopted specification defined for electrocardiography. The instrumentation amplifier provided enough gain to amplify the signal without saturation occurrence. Bessel topologies were chosen due to the preservation of the signal morphology. The high pass filter is set to a cutoff frequency of 0.1 Hz in order to block the DC signal that resulting in baseline oscillation. In the low-pass filter, the cutoff frequency was very close to the projected 120 Hz, since the amplitude of the signal at that frequency had a value equivalent to 0.707 times the input signal. The notch filter, because it required high-precision components, had its cutoff frequency slightly shifted slightly above 58 Hz. Still, it resulted in good noise filtering at the same frequency. The signal captured from the body, with the use of surface electrodes, continued with a certain level of noise even after the filtering process. Even so, it was possible to correctly visualize the P and T waves and the QRS complex, proving the efficiency of the circuit.

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